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DIFFUSION, R&D AND PUBLIC POLICY: IS IT BETTER TO BE A FIRST MOVER OR FAST SECOND?

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ABSTRACT: There are three positive questions discussed in the paper. First, R&D incentives, financing prospects and the resulting equilibria are characterized. The focus is especially on risks, risk sharing and on the external effects. Second, the paper addresses to what extent competition creates incentives for R&D investments and whether the current market power of a firm interacts with its innovative effort. Third, regularities as to the rate of diffusion are summarized and some explanations suggested. Next, the normative issue is raised whether a decentralized market system provides sufficient incentives for R&D. The conclusions point in the direction that even if the race for patents gives rise to substantial competition for innovations strengthened by R&D policies chosen strategically in open economies, these policies can also be motivated by the inefficiencies in the operation of risk markets and the substantial positive externalities that both R&D efforts and diffusion have in the economy. However, since the "fast second" approach is typically much less risky than is the policy based on being a "first mover", the choice here is a matter of social attitude towards risk.

KEY WORDS: Technical change, R&D incentives, R&D policies, Diffusion of innovations

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1. Introduction

When a firm buys a machine, it does not buy a piece of steel, but rather a piece of knowledge. Diffusion and R&D effort can in most cases be viewed as substitutes for the firm in acquiring improved technology. Their basic difference is that the risks attached to an R&D effort may be substantially higher. When a firm buys a machine, the technology is there and it has probably been tested by other firms. Indeed, by diffusion, the firm can tend to maintain its competitive position in the market. By an R&D effort, it aims not only to maintain but also to improve its market position.

Diffusion means that firms are willing to pay the rent to the inventor. R&D effort means that the firm is willing to take a chance of entering into a risky project. In the latter case, it can itself try to capture the rent either by selling the invention to other firms (through the patent rights or licensing) or it can set up a production unit by itself and capture the rent through the market place.[1] The rent apparently is adversely affected by the capability of competitors to imitate.

In a broad sense, an R&D effort by firms can be thought to cover all the actions that are directed to improvement of production efficiency, including organizational and social innovations. R&D may involve undertaking of research aimed at process innovations that will reduce the overall costs. It can also be research on new products or product design such that better products can be produced out of given resources.

Innovative activity, when successful, gives rise to accumulation of new knowledge embodied, in the first place, in human capital. By its very nature, the new knowledge capital typically is not firm-specific. Quite the contrary, there may be a substantial social value attached to it outside the innovative firm. It is the social externality associated with a successful R&D project which distinguishes it in an important way from other types of investment projects.

By its fundamental nature, an R&D effort represents a leap into the unknown. It is a good guess that R&D projects tend often to be much more risky when compared to investment in the assets using existing technology. Moreover, the risk is due to factors that are rather difficult to be observed or monitored by the external markets or outsiders. Hence, risk asymmetries between the entrepreneur and the external risk market are likely to be more prevalent for R&D investments than for other types of investments. The risk associated with an R&D project is strongly dependent on entrepreneurial characteristics that are not easily verifiable, like the entrepreneur's innate abilities and the amount of effort that he puts into the project.

Asymmetric information between entrepreneurs having good ideas and the external capital market providing funds and relieving the entrepreneurs of risk, raise both positive and normative questions. On the positive side, one would like to have a theory explaining how the markets work as to the allocation of resources for R&D. This research task involves characterization of the R&D incentives, the financing prospects of the R&D projects and the resulting equilibrium. This is the first issue discussed in the paper in section 2 where the problems in financing of risky investments are studied, production of knowledge is scrutinized and the potential correction of the allocational distortions is addressed.

A second positive question concerns the impact of competition on the rents from the innovative effort. In particular, the industrial structure can be expected to be highly relevant for the incentive structure. Hence, section 3 focuses on the question whether competition between firms creates incentives for R&D investments and whether the current market power of a firm interacts with its innovative efforts.

A third positive question addressed is the issue of diffusion. In section 4, the empirical regularities as to the rate of diffusion are summarized and the suggested explanations for the lags between innovations and their adoption are provided. Moreover, a normative question is raised concerning the socially optimal rate of diffusion.

On the normative side, one would like to evaluate whether a decentralized market system provides sufficient incentives for R&D in light of a properly defined social welfare criterion. In particular, one would like to understand the reasons for potential market failures and the potential ways of improving the market allocation through public policies.[2] Casual empiricism suggests that the western economies have been technologically superior to any other civilization so far. The most plausible hypothesis is that this outcome is a result both of the way in which the property and patent rights have been established and the industrial structures promoting competition. Yet, industrial policies aimed at futher promoting both the R&D effort by private firms and encouraging them to speed up the diffusion of new innovations are widely and extensively used. Section 5 presents some general ideas on industrial policies with respect to R&D.

It is not the case that only firms would enter the competition for innovations. Governments equipped with national policy targets may behave strategically. The tax systems can be structured for this purpose. Whether the national interests and the international efficiency are in conflict will be taken up in section 6 of the paper.

Section 7 provides a summary of the conclusions obtained in the paper.

2. Do Markets Function Properly in Allocating Resources to R&D?

2.1 Production of Knowledge

As to the allocation of resources to the production of knowledge, two types of concerns have been identified ever since the pioneering article by Arrow [1962]. One is due to private risk aversion to be discussed below. The second is the appropriability problem in that too little resources may be allocated to R&D because knowledge is a public good through imitation. To provide incentives for production of knowledge, mechanisms have been created for the innovator to capture some of the social value of new knowledge by restricting its use, say through patents and licensing. This creates a second best trade off between the optimum production of knowledge on the one hand and the optimum use of knowledge on the other. We suggest that a second best optimum would probably involve some inefficiency both with respect to production of new knowledge and with respect to utilizing the existing knowledge.

The usual claim that an R&D project is more "difficult" than an investment in ordinary assets can be identified with the difference in the relative riskiness. The intangibility aspect suggests that R&D investments will have a particular return structure both from a private and social point of view. We put forward the following propositions:

(i) In most cases, R&D activity is aimed at making some invention or technological breakthrough. If the project fails, the resources spent on the project may be considered as a waste from a private point of view. Hence, the liquidation value of R&D is zero when the project fails. So, an R&D investment may yield a high private return with a small probability and a return of -100% with a high probability, being thus more conducive to higher risk as measured by the variance of the returns. In the case of an investment in existing technology, some positive liquidation value usually emerges because the tangible assets may have economic value in some alternative use.

(ii) Most R&D projects are indivisible in that they do not yield any payoff until they are completed. That means that R&D investments are irreversible so that the only way to recuperate the funds invested in the project is to turn it into a success. This imposes an extra risk premium on R&D projects in the form of an option value for reversible or liquid investments.

(iii) By its very nature knowledge is a public good, which makes it difficult for the entrepreneur to appropriate the full social value of new knowledge. If the project turns out to be a success, this value can be appropriated, or internalized, through patents and licensing. If the project fails, it is a waste of money for the entrepreneur but the negative result may nevertheless be useful for the society. Hence, there is a market distortion in the sense that the value of positive results can be appropriated whereas the informational value of negative results cannot. From the social point of view this may be a problem if it distorts private R&D activities towards projects with high success probabilities.

It is, however, not always the case that the social return would exceed the private return. Examples can be given as to when their covariance is actually negative, though this is not the typical case.

(iv) Investment in R&D means creation of intangible capital that may be difficult to collateralize, and in the case of failure, R&D investment destroys collateralizable wealth. This means that as to R&D, the lenders have to rely more on other assets of the firm to obtain the required collateral for funds channelled to R&D projects.

(v) Successful R&D projects enhance the productivity of the entrepreneur's material resources. Apart from that, they also contribute to the stock of knowledge in society and thus have positive effects on other firms. As pointed out by Romer [1986] that might imply increasing returns to scale from the society's point of view. Hence, private incentives for R&D are crucial for long-term productivity and growth. Another aspect of the public good nature of R&D projects is that they may create a gap between private and social risks. The individual entrepreneur is underestimating the true returns if the project succeeds, and if the project fails the mere fact of a failure may be of public interest even though the individual entrepreneur cannot capitalize on that.

(vi) The assets created through R&D are, in the first place, embodied in the human capital and for that reason are not firm-specific. Their economic value outside the firm adds to the riskiness of the R&D project since human capital is a mobile factor. More concretely, the ideas may be captured by the competing firms by buying, say, some of the research staff from firms undertaking R&D investments.

(vii) The risks involved do not stem only from the technological aspects of innovation activity. Competition and the demand in the market for the final good is another source of uncertainty. The latter, however, is common to R&D investments and conventional investments.

(viii) The major inputs in innovative activity include the stock of existing knowledge and the R&D effort (cf. Kanniainen [1990]). It is, however, more common to assume simply that a successful R&D project reduces a firm's costs of production instead of modelling the production function of innovations explicitly. The innovation activity, when modelled, can be thought to exhibit decreasing returns to scale, i.e. doubling the R&D effort probably results in less than a proportional expected increase in the flow of new innovations. For example, once the penicillin has been invented, it is much harder to develop anything comparable.

2.2 The Financing of Risky Investments

There is a substantial body of literature on the types of equilibria emerging in the case of financing risky projects under asymmetric information. Informational asymmetry means that insiders (entrepreneurs) know more about the project ideas than do the external markets. That is true both with respect to the actual choice of project as well as to the amount of effort the entrepreneur plans to put forth in order to make the project succeed. That creates a double moral hazard problem as risk shifting through an external risk market affects the entrepreneur's incentives both with respect to effort and project choice.[3]

On the financing side, firms may be constrained to resort only to debt and internal equity (retained earnings) in financing R&D investments. The existence of bankruptcy risk imposes, however, a limit on the firm's loss in the case of failure. On the other hand, all the extra profits will accrue to the firm in case of a success. Hence, borrowing and bankruptcy risk induce the firm to choose more risky projects as the firm does not bother about the loss inflicted on the lender in case of bankruptcy (cf. Jensen and Meckling [1976]). It may not be optimal for the lender to compensate for this through higher interest rates as this will on average attract more risky borrowers (cf.Stiglitz and Weiss [1981]). Hence, the entrepreneur may be rationed also in the loan market[4], in which case he has to rely entirely on internal financing.

The failures of equity and credit markets limit the possibilities of firms to diversify the risks associated with R&D investments and lead to a reduction in productivity-enhancing investments as an alternative means of risk management. A substitute for external financing provided by new owners has to be found from internal sources, i.e. from retained earnings belonging to current owners. The efficiency loss in risk diversification can, to some extent, be reduced if the firm is simultaneously engaged in several uncorrelated projects. This may, however, require an expansion in the scale of the firm over the optimal size emerging under efficient risk sharing. Indeed, large firms seem often to be those which are most R&D intensive. At the benefit side, some monitoring gains may emerge creating economies of scale for R&D activities.

Fundamentally, the allocation of resources to R&D activities is a principal-agent problem. The problem is that the optimal financing contract should solve simultaneously both the incentive problem and the risk sharing problem. As these problems are deeply rooted in the organizational set up of the society, it may be somewhat inadequate to call these problems market failures. It may be more relevant to compare the market solution with that implemented by a social planner aimed at maximization of social welfare but being constrained by the same informational asymmetry between the savers providing the funds, and the entrepreneurs providing the ideas.

2.3 R&D and Financial Market Imperfections

2.3.1 Adverse Selection

The problem of adverse selection has been extensively analysed in the models of credit contracts. In the current context, it may be assumed that firms have access to different technologies in production of innovations. This may be because there are differences in the ability of the innovators in producing "new ideas" and/or the creativity of the research staff may vary from one firm to another. Differences in ability will lead to a different payoff structure. In other words, interfirm differences may be reflected in the probability of success.

Fundamentally, the adverse selection problem arises because the external market (banks, stock markets, etc.) does not have costless access to information that would reveal the true nature of the idea and the quality of the firm to evaluate that idea.[5] We are, however, inclined to suggest that the R&D problem does not really add any new dimension to the standard problem of adverse selection.

2.3.2 Moral Hazard

Moral hazard with respect to R&D can arise in a variety of ways. As the firm normally has access to an array of R&D projects with varying risks, it can reoptimize its choice among projects after the contracts have been signed.[6]

Another type of moral hazard arises when capital investment is not the only input required in R&D projects but effort is required as well. One would expect this to be typical of most R&D projects which are dependent on the entrepreneurial supply of good ideas. It is also to be expected that effort is more difficult to observe and monitor in this context because the supply of effort takes the form of providing intangible factors like good ideas that only materialize when they turn out to be a success. Financial structures relieving the entrepreneur of some of the risk would at the same time be detrimental for the incentives as he will not get the full private profit in case of success.

2.4 Potential Allocational Distortions

R&D activities display all the usual problems related to adverse selection and moral hazard in principal-agency relations involving risk and asymmetric information. Indeed, it may be claimed that the information asymmetry is a more serious problem here because of the very nature of the effort as an input. Hence, rationing in external financial markets is more likely in this area than for more tangible types of investment. Yet, it may be claimed, as in Romer [1986], that the gap between private and social returns is greater for investment in intangible capital generating returns that cannot easily be captured by the investor. This distortion will be aggravated by the distortions created by moral hazard.

The question is, however, whether the problem is an inherent feature of the technology structure of modern societies or whether it is a defect of the market system. In the latter case it can in principle be corrected by public policy whereas in the former situation it is not so obvious that a social planner aiming at maximizing social welfare could do better. The general problem is how to define the allocational benchmark in a situation with asymmetric information. If policy tools exist for bridging the informational gap between entrepreneurs and the external capital market, it remains to be shown that these tools will not be utilized by the profit-motivated capital market.

It seems that the more convincing arguments for governmental policy lie on the benefit side through the difference between private and social returns. In that respect, the case for government intervention is the same as for public goods and positive externalities in general.

The informational problem may lead to the entrepreneur being rationed in the external capital market. Hence, he has to bear all the risk associated with R&D activities. Under limited possibilities of shifting risks to the external risk markets, the government could conceivably rectify this by alleviating the riskbearing of the entrepreneur through having some of it born by the taxpayers.[7,8]

It is, however, an open question whether the government is better informed than the capital market. If not, social costs associated with moral hazard and adverse selection in connection with R&D activities may be an equally challenging problem for the government and private capital market. In other words, there is an informational asymmetry between the public controller and the private research-oriented firms. The controller does not necessarily know which firms have the most efficient research departments or which one are those which are most motivated to provide the required research effort. This gives rise to another type of adverse selection and moral hazard that has so far eluded theoretical analysis.

3. R&D Competition

There should be no doubt that the most important incentive for private firms to allocate their resources into R&D projects is based on the profit motive. This motive has been the major engine in the economic growth in market economies. However, the strength of this motive is highly regulated by various factors associated with the industrial structure of the economy.

It was argued by Arrow [1962] in his seminal and influential article that for a drastic innovation (one which leaves the inventor a monopolist), an incumbent monopolist would have less incentive to invent than would an inventor who is not in a dominant position. The subsequent literature surveyd by Reingamum [1989] and focusing on the issue raised by Arrow has qualified his suggestion.

The issue of competition for a patent has been analyzed over the past decade both within the so-called auction paradigm and the race paradigm. In the auction paradigm, the firms are assumed to compete through bidding and the firm with the highest bid is assumed to undertake the R&D investment. In the race paradigm, all firms are commited to an R&D race. The key idea in both approaches that the cost of invention is a decreasing and convex function of the time prior to invention. In the former paradigm (Dasgupta and Stiglizt [1980]), a number of firms are "bidding" for the right to produce the invention. In the latter, a commitment of funds today determines the eventual date of invention. The stochastic formulation was first provided by Lucas [1971] and Kamien and Schwartz [1971] though in the case of a single innovating firm.

The message of the auction and race models is that the firms tend to invest in R&D at a higher rate than is jointly optimal (Loury [1979], Dasgupta and Stiglitz [1980]). This follows from the nature of the noncooperative Nash equilibrium. However, when the number of firms increases, the equilibrium level of a firm's investment in R&D declines. Moreover, the expected time for invention falls. If the entry is unrestricted, there tends to be too many firms relative to the cooperative optimum reached by a joint venture.

The excessive investment in R&D which is implied by these models arises out of two sources. First, each firm has the incentive to win the race. Hence, there will be excessive duplication of effort since, unlike in the case of a joint venture, each firm tends to ignore its impact on its rival's payoff. Second, there will be too many firms competing relative to the cooperative equilibrium. It should be noted that all these results carry over but only partially to the social valuation, since no firm is assumed to possess any monopoly power. From a broader point of view, the positive spillovers between firms in the use of the inventions have to obtain their proper weight in social evaluation.

The above results hold even if one of the firms would be the dominant player in the sense of a first mover or Stackelberg leader. The important lesson especially from the auction model is that the competition may be keen although one does not really observe any race. It is not only the observed actual competition which is relevant for the innovative incentives: equally important is the potential competition.

However, one should not forget that the strong results reached above have been obtained under the assumption that the patent protection is perfect. Indeed, the extent of appropriability is essential for the incentives to invest in

R&D as claimed already by Arrow [1962]. As confirmed by Reinganum [1982] when the patent protection is ineffective, there will be no R&D effort. From the practical point of view, the patent protection can hardly be perfect notwithstanding the fact that a perfect protection would be socially suboptimal in the sense of underutilization of new knowledge.

The models where some firms have more market power than others may be more relevant from the practical point of view. The results available obscure to some extent the message obtained in the models with equally strong competitors. As the survey by Reinganum [1989] shows the uncertainty in the production of innovation is crucial here. When innovation is uncertain, a firm which currently enjoys a large market share will invest at a lower rate than does a potential entrant for an innovation which promises the winner a large share of the market. If, however, there is no uncertainty, it is the opposite which is true.

The presence or absence of uncertainty also determines whether the role of technological leader will circulate around the industry or remain in the same firm. Often innovations come in sequences. The effect of anticipated future innovation is also affected by the uncertainty in that the incentives to win today may be reduced since it is not sure that today's winner will prevail in the next race. In the deterministic case it is, however, absolutely crucial to be the winner in the first race. If the race is of the multi-stage game type, a technological lead is highly valued especially if the innovation is deterministic. Again, uncertainty may change the situation since the outcome depends both on the R&D effort and the risks involved. A firm which has put less effort in the project may come out as the winner.

The lesson from these results is not easy to judge. Uncertainty affects differently the R&D effort of firms which have different market power. Firms with a large market share and technological lead tend to put effort in the R&D when the outcome is predictable while the potential new competitors may want to be the lucky ones by taking the advantage of the uncertainty attached to the innovation process.

4. The Diffusion Mechanisms

When a new technique or product has become available, it can be adopted through two channels. First, the number of producers or net entry may change. This is what Gort and Konakayama [1982] have called diffusion in the production. They also provided empirical results as to the explanatory factors with respect to entry. The second type of diffusion emerges when the existing firms adopt the new technique or product. The empirical regularities as to the diffusion of the latter type can be summarized as follows:

(i) If the extent of diffusion of a new technology is measured as the proportion of potential users that have adopted that technology by a given date, the time profile of the diffusion curve tends to be S-shaped. The classic references are Griliches [1957] on hybrid corn and Mansfield [1968] on 12 industrial innovations. The proportion adopted is an increasing function of time which is initially convex but eventually becomes concave.

(ii) The diffusion curves tend to be right-hand skewed in that the curve is concave over the greatest amount of time.

(iii) Many inovations tend to be adopted sequentially rather than simultaneously (cf.Kapur [1991]).

(iv) Many studies have concluded that diffusion is faster for innovations with higher profitability and that large firms tend to be the earliest adopters.

The diffusion is a process rather than an instantaneous event suggesting that there is a positive lag between the date when a new technology has become available and the time of its adoption. Moreover, different firms tend to have different lags. The reason for the differentiated lags has been explained in terms of heterogeneity in initial beliefs and the desire to gather more information (Davies [1979], Jensen [1982]). Alternatively, it has been suggested by Kapur [1991] that the regularities can be explained by the initial technological uncertainty as to the true technical characteristics of the innovation and by the potential irreversibility of the adoption decision.

Reingamun [1981] proved that the diffusion phenomenon may also arise in a symmetric duopoly game between identical firms. If a cost-reducing innovation is adopted by a firm before the other firm the former can make a substantial profit. However, the firm that waits may save money on the cost of purchasing the new technology. This follows if the discounted sum of purchase price and adjustment costs decline with the lenghtening of the adjustment period as quasi-fixed factors become more easily variable. It is indeed plausible that the diffusion decisions are chosen strategically, i.e. firms take into account the decisions of their competitors, (cf. also Fudenberg and Tirole [1985]).

The literature above suggests an important message. The time pattern of diffusion is much more than a statistical phenomenon. It is rather an outcome of economic incentives prevailing in the market system. Consequently, it cannot be regarded as immune to industrial policies. Unfortunately, not very much is known about the appropriate tools for favoring the diffusion of fruitful innovations and postponing adoption of potentially secondary innovations. Moreover, not very much is known about the socially optimal rate of diffusion. Since all investment decisions bear some opportunity cost, it is possible to argue that though a high rate of diffusion is desirable, the maximum rate may not be socially optimal. Obviously, the social behefits and costs behind the optimal rate of diffusion require closer examination.

5. Policy Tools for R&D

5.1 Alternative Approaches

It is a general insight from the theory of externalities and government intervention that the policy tool should be tied as closely as possible to the sources of the externality. Hence, when it comes to R&D, one has to ascertain whether the externality is due to the wedge between private and social returns (the Romer argument), or whether it is due to a wedge between private risk taking in unregulated risk markets and socially desirable risk taking, or both.

The increasing returns argument for investment in R&D calls for subsidizing the private revenue from R&D in order to correct private incentives. That could be done by having the government pay a bonus on (ex post) successful R&D projects. That could, for example, be achieved by preferential tax treatment of returns on R&D investment. The particular way in which the bonus is constructed is apparently highly important for the incentive effects. The practical difficulties should not, however, be underestimated.

Some countries like Finland have earlier experimented with a special tax deduction. Rather than being a bonus on successful projects, a tax subsidy was related to a firm's R&D outlays representing an ex ante risk sharing with the taxpayers. While the R&D outlays normally qualify for free depreciation this additional tax base adjustment, proportional to the R&D expenditures, was thought to close the gap between the private and social required rates of return on the R&D investments. The major drawback associated with this type of tax reduction was due to that it was automatic and unrelated to the type and social value of the projects.

Inefficient risk bearing due to rationing in external risk markets could in principle be mitigated in various ways. The government could take on some of the risks by guaranteeing the entrepreneur some minimum returns from R&D investment. This is in fact the procedure followed, for example, in the U.S.A. by contracting out R&D activities to private firms on a cost plus basis. That means that the government guarantees that the entrepreneur gets the minimum profit laid down in the contract. The economic significance of this type of contracts is that the left-hand tail of the probability distribution for returns is eliminated. In principle, that works very much like the case of borrowing without collateral, although there may be negative incentive effects as to effort and project choice depending on the generosity of the terms of the contract. This need not, however, be the case at least in the model where the government knows the quality of the firm.

A perhaps more subtle way to mitigate distortions related to asymmetric information might be to subsidize the monitoring activities of lenders. This could for instance be accomplished by subsidizing the bank's acquisition of scientific expertise so that the bank becomes more able to assess how funds for R&D investment are spent. The economic effect would be reduction of the informational gap between the entrepreneur and the bank, and hence this would attack more directly the source of the negative incentive effects.

Any public policy has to be associated with the evaluation of the social costs of the policy. In particular, measures like subsidization lead to the need to raise revenue through distortionary taxes. Moreover, since taxes in turn may interact with interest rates it is not always easy to judge the ultimate incidence of tax-financed subsidies.

Though a public controller will face the same kind of adverse selection problem as do the private risk markets, there are some reasons why an outsider public controller may be very useful in evaluation of projects and in the decision process as to which projects are to be financed. First, a central coordinator may have an informational advantage due to the very fact that it may be in a position to evaluate a substantial number of independent projects simultaneously. Moreover and by implication, this may reduce the problem of duplication of effort. Second, while the inventing firms may not want to release too much information to private financing units, it may be that more relevant information on projects may be made available to the public coordinator.

5.2 R&D Policy in an Open Economy

The case of an open economy raises several important and new issues as to the R&D when compared to a closed economy. First, some factors like capital not to mention the R&D capital are highly mobile between countries. This means that also the tax bases are mobile. Moreover, the major economic justification for public policy towards R&D as suggested in the existing literature may break down. The positive externalities attached to domestic R&D may benefit the foreign competitors due to imitation and information leakages. From a policy point of view, the leakages are less problematic in closed economies, where they in a sense reflect internalization of the external effects. Second, given that countries are interested in their internal welfare in a world of unharmonized tax structures, tax competition may lead to strategic interactions between the governments. This concerns public support for R&D effort, too.

The policy problem in an open economy can be described as follows. Domestic firms compete with foreign firms for market shares in world markets which are more or less integrated. They can be expected to choose their R&D effort strategically, i.e. they know that their profits depend upon the actions undertaken by their foreign competitors.

One aspect of the international perspective is the optimal location both of the production units and the research units. The research activity is directed to improve the firm-specific technology whether utilized by the domestic parent companies or foreign subsidiaries of the domestic parents. It is appropriate to think that the technical know-how is fully mobile between the parents and the foreign subsidiaries while the leakage of information between domestic and foreign firms is a matter of appropriability.

It is useful to think that the equilibrium emerging from the competition between domestic and foreign firms is of the Nash type. The reason is that the international coordination of research activities of different firms seems highly unlikely at least in the areas where the production is not monopolized. The important conclusion follows that the allocation of resources to R&D will not satisfy the conditions of international efficiency. It seems indeed plausible that due to competition, excessive resources may indeed be directed towards the R&D effort from the point of view of international efficiency, as was discussed in section 4 above.

The policy problem of national governments arises due to the mobility of factors of production. National interests dictate that each government wants sufficient amounts of production units to be located on its territory because of employment reasons. It is useful to think that the interaction of national policies is formulated in a strategic manner. Indeed, tax competition which has obtained increasing attention over the past few years is becoming an important mechanism for reallocation of capital internationally. In the absence of international policy coordination, all national governments decide on their subsidies and tax policies purely from the perspective of national interests. Potentially, this adds to the inefficiencies from the international perspective in that individual rationality (a single country) and group rationality (the international community) are conflicting. The national benefits from subsidization of domestic R&D efforts heavily depend upon those international spillovers which cannot be appropriated by domestic firms. With strong leakages, domestic R&D subsidies may fail to create the technological advantage that the national governments are aiming for. That may give rise to the "free rider" approach. From a purely national viewpoint it may be justified more to encourage diffusion of modern technology from abroad to the benefit of domestic firms rather than trying to win a genuine R&D race, where the "winner takes all" principle means substantial risks. Social evaluation of risks may thus dictate that "the fast second" approach is superior to "the first mover" policy.

6. Summary

The major question addressed by the current paper was whether sufficient resources are allocated to R&D and to diffusion in market economies. We also addressed, though in an more superficial manner, the question of the alternative approaches to appropriate policy tools.

There is no doubt that the competition of private firms for innovations and the associated patents is the major explanation for the rapid technical progress and economic growth in western market economies. This was our topic in section 3. Additional fuel to this race are provided by the uncoordinated industrial policies of national governments which subsidize the innovative activities through various channels. This race is not, however, without some social costs in that there may be excessive duplication. Moreover, the adverse selection problem faced by the public coordinator creates some unavoidable inefficiencies, though from another angle a public coordinator may be in a better position than are the private risk markets in the evaluation of projects which need external finance.

In spite of the race mechanism, it is not clear that it is advisable to leave the innovative activity to the market forces only. There are also important constraints on the incentives to carry R&D programs, as discussed in section 2. First, we have pointed out that firms which are in a strong market position may have limited incentives to innovate, especially if the R&D investments are highly risky. Second, asymmetric information may create binding constraints for the possibilities to finance R&D projects. Third, patent protection is never perfect, which creates the appropriability problem. While this is an incentive problem of the innovating firms, the imperfect appropriability is socially valuable in that innovations carry important externalities elsewhere in the society.

Public support for private R&D programs and acceleration of diffusion is based on the view that considering all the above mechanisms, there will be too little R&D effort on an aggregate level, too little risk-taking and unoptimal risk sharing relative to the social optimum. This view derives from the substantial positive externalities that both R&D efforts and diffusion process have in the economy and the society. The public coordinator, however, faces the problem whether the financial support for R&D or diffusion should be channelled in terms of credit with limited liability property or in terms of equity, or as a mixture of both. Our discussion in section 2.2 shows that the associated incentive effects may be rather different as participation in equity entitles shareholders to a corresponding share of the return on R&D while in the case of a debt contract the firm owns all return that exceeds the debt interest. Of course, risks are also shared differently in that an equity contract consigns shareholders to the position of residual claimant only.

While it is possible to argue that support for R&D and diffusion may have substantial social payoffs, the choice between these two alternative policy strategies apparently is a matter of social attitude towards risks. Indeed, it is important to emphasize that the "fast second" approach is usually much less risky than is the policy based on the "first mover" target.

Footnotes:

1. The institution of patent protection has been developed to guarantee sufficient appropriability. The patent system as we know it today was not conceived until 1852. Prior to that there is a period of over 500 years in which patent monopolies were granted quite often to inventors but not necessarily because they were inventors (see Phillips and Firth [1990]). The first English patents were granted in 1331 to foreigners who wished to practise their crafts in England.

2. Reasons for real distortions caused by social externalities or capital income taxes have been studied earlier by Hagen and Kanniainen [1990]. However, as far as we know, Greenwald and Stiglitz [1990] is the only study on distortions due to asymmetric information.

3. As shown by Leland and Pyle [1976], Myers and Majluf [1984], Greenwald, Stiglitz and Weiss [1984], external equity markets will function imperfectly in such cases and firms may be rationed in these markets.

4. It has been possible in some cases to characterize the optimal type of credit contract between a risk neutral bank and a risk neutral firm (Williamson [1987], Gale and Hellwig [1985]). The cost of monitoring and the possibility of adverse selection or moral hazard may lead to allocational distortions in the sense of underinvestment or credit rationing (Bester and Hellwig [1988]). However, it may be possible for the bank to screen the entrepreneurs by offering differentiated contracts so that the borrower reveals his type by acceptance of a specific loan contract. Loan size (Milde and Riley [1988]) or size of collateral (Bester [1985]) can be used as additional instruments for the banks in supporting a separating equilibrium. Differentiation of borrowing contracts may solve the adverse selection problem arising from a bank's inability to know the quality of the entrepreneur with respect to R&D activities. The double moral hazard problem will nevertheless remain, leading to a socially suboptimal risk sharing as to the R&D as compared to the first

best allocation.

5. One can think of designing contracts that provide incentives for revealing the true type (truth-telling is typical in any Pareto optimal contract). If the external financier has more than one instrument to be included in the contract, this creates possibilities for entrepreneurs with good ideas to signal their type. In that respect, the R&D project is like any other risky project.

6. Since equity capital is like a call option, the value of which increases with the variance of the returns, and since a firm in its financial policy is maximizing the equity value instead of its total value, the initial shareholders would benefit if the firm switches from a less risky to a more risky project. Under debt financing, the bank only gets the lower tail of the distribution of returns while the shareholders get the upper tail. Those supplying finance to the firm will, of course, anticipate the moral hazard. It is then rational to adjust the credit terms ex ante through the collateral or internal equity requirement.

7. An income tax may induce higher private risk taking if the losses are shared with the public sector. Moreover, it may be that a tax on, say savings, will reallocate financial resources between low-ability firms and high-ability firms. In particular, since a pooling equilibrium typically means a subsidy on low-ability firms, higher taxes may, surprisingly, improve the efficiency.

8. Another remedy for mitigating downside risk could be for the government to guarantee the fullfillment of private loan contracts for financing of R&D. In principle, that can be regarded as outside collateral provided by the government. For the entrepreneur, the adverse selection and moral hazard still remain. But the costs of these incentive problems are to some extent shifted to the government and to the ultimate taxpayers.

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